INSPIRING-SNI: Investigating SDN Programmability Improving Optical South- and North- bound Interfaces

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ABSTRACT
Software Defined Networking (SDN) controllers decouple the forwarding data-plane actions, instructed via south-bound interfaces (SBI), from the logic control-plane decisions, which can be decided by network applications exploiting the north-bound interfaces (NBI). This paper overviews the achievements of INPIRING-SNI, a Marie Sklodowska-Curie Action that aims at enhancing programmability in optical SDN ecosystems from two perspectives: SBI for interacting with optical equipment and NBI for exposing programming abstractions that ease the development of network applications. INSPIRING-SNI focused on disaggregated approaches for SBI based on YANG models while proposing an innovative approach for the NBI based on the concept of network optimization as a service (OaaS) with an extension of the Net2Plan planning tool.
Keywords: API, Marie Sklodowska-Curie Action, Optical Networks, Optimization, SDN.

1. INTRODUCTION

Telecom operators (also known as *carriers*) have their network infrastructure composed of multiple domains, multiple technologies and equipment from multiple vendors, which poses numerous operational challenges. Additionally, the ever-increasing traffic volume and dynamicity further stresses the operations in such a complex infrastructure that includes a mix of services, layers, protocols, while requiring the support of new client demands or new business models. Traditionally, carrier networks couple control plane decisions on how to handle traffic with data plane traffic-forwarding actions. This approach reduces flexibility, favours vendor lock-in, and limits innovation and network infrastructure evolution.

During the last decade, software defined networking (SDN) has proven to enable an unprecedented level of network programmability by decoupling the forwarding data-plane actions from the control-plane decisions [1]. Notably, SDN offers a global network view that can be exploited by network applications (see top part in Fig. 1) for defining policies according to traffic needs, thus potentially overcoming the limitations of current network infrastructure and enabling many new functionalities and optimization opportunities [2], for instance based on the open-source Net2Plan planning tool [3]. Such enhancement of network infrastructure capabilities is based on two types of application programming interfaces (APIs).

On the one hand, south-bound interfaces (SBI) are exploited by the SDN controller to govern the behaviour of data plane elements. A clear example of SBI is the OpenFlow protocol [4] employed in packet networks to update packet handling rules in the flow table which governs the switches. In optical networks, the common approach is to deploy a software *agent* tightly coupled to the data-plane element so that standardized SBI commands are translated into hardware-specific actions (see bottom part in Fig. 1) [5]. Current trends are consolidating agents based on OpenConfig [6] and OpenROADM [7] models that employ Yet Another Next Generation (YANG) templates [8] combined with NETCONF [9]/RESTCONF [10] protocols over the usage of OpenFlow extensions for the optical domain [11].

On the other hand, in the upper side of the SDN view in Fig. 1, the north-bound interface (NBI) offers a common programming abstraction to the upper layers (e.g., network applications) abstracting the low-level instruction sets used by SBI to program forwarding devices [1]. Since the adoption of the network application model shown in Fig. 1 was only possible after the advent of SDN controllers and therefore made available after the first efforts in the standardisation of the SBI, NBI as an enabling technology is yet an open and recent challenge, with the existing implementations being not as consolidated and mature as their SBI counterparts. NBI alternatives range from standardized options such as *Transport API* (TAPI) [12] that exposes a number of services, ETSI drafts [13], up to native and extensible APIs of SDN controllers such as ONOS [14].

In this paper, we overview the major outcomes of *Investigating SDN Programmability Improving Optical South- and North- bound Interfaces* (INSPIRING-SNI), a two-year Marie Sklodowska-Curie Action (MSCA) [15] funded by the European Commission [16] that aims at enhancing programmability in optical SDN ecosystems[17]. In Section 2, we provide the global view and major areas of interest in INPIRING-SNI. Section 3 reviews our major contributions regarding the SBI of SDN-enabled optical networks. Section 4 highlights our NBI contributions and main SDN network application for optimization purposes. Section 5 covers our major achievements encompassing experimental demonstrations and the full control stack from SBI up to NBI and network application. Section 6 summarizes the paper.

2. INSPIRING-SNI GLOBAL VIEW

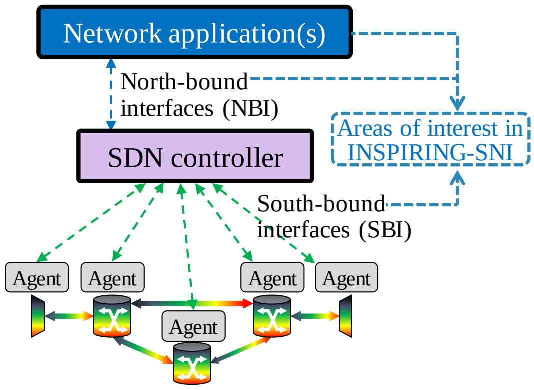

Figure 1. Simplified view of an SDN architecture and areas of interest in INSPIRING-SNI.

Fig. 2 accompanies the simplified view of an SDN architecture with the three major areas of interest in INSPIRING-SNI. First, SBI modelling, functional aspects and control characteristics are of interest because they permit the interaction with optical network equipment at the data plane. Second, the modelling abstraction performed at the NBI is relevant as it impacts the network programmability offered by the SDN controller. In fact, it is important to ensure that SBI characteristics are considered both at the SDN controller and at the NBI so that network applications can leverage on their capabilities crucially for on-line resource allocation decisions and potentially for long-term off-line capacity planning and network dimensioning evaluations. Third, network applications are envisioned in INSPIRING-SNI as the host for optimization approaches for efficiently employing the resources available in SDN-enabled optical networks. In the following, we overview INSPIRING-SNI's major contributions, which take the form of theoretical analyses, software developments, experimental demonstrations and studies with simulation frameworks. We follow a bottom-up approach.

3. SBI CONTRIBUTIONS

INSPIRING-SNI began with an invited paper that overviewed the initiatives and trends in SBI [18]. In particular, [18] reviewed the avaialbe alternatives for SBI to control optical components whose early stages were between 2012 and 2014 with ad-hoc extensions of OpenFlow, but that subsequenty pivoted toward YANG modelling proposals combined with the NETCONF and the later RESTCONF protocols. Furthermore, we covered different tools and frameworks available for quick prototyping and deployment of software services that are compliant with such interfaces and protocols. Specfically, we identified the major components and characteristics present in the two dominant frameworks: ConfD and Netopeer2/Sysrepo. Finally, [18] also discussed the advantages and drawbacks of the reviewed initiatives.

Subsequently, in the context of INSPIRING-SNI, [19] provided two major contributions. First, it included a gap analysis between different YANG-modeling alternatives (e.g. OpenConfig [6] and OpenROADM [7]) by identifying their completeness both in terms of operational and inventory points of view. Second, it experimentally demonstrated the overall architecture with two Nokia transponders and an ONOS instance located at Telefonica facilities (Madrid, Spain), which exposed an NBI for a Net2Plan-based network application executed at Cartagena laboratories (Spain).

Recently, our invited paper and talk [20] reported our preliminary advancements towards an optical emulation framework built on top of a module that permits the automatic creation of agents for optical equipment. Specifically, we leveraged on a set of automatically created Cassini agents to form a Docker-based network topology underneath an ONOS instance, i.e. employing a NETCONF-based SBI.

4. NBI AND NETWORK APPLICATION CONTRIBUTIONS

In terms of NBI, [19] included a brief discussion on two available alternatives at the time of that publication: TAPI that pursued an increase of the optical technology visibility, thus potentially enabling quality-of-transmission (QoT) estimation [12]; and an IETF draft that proposed a YANG model for extending the optical characteristics of the Traffic Engineering topology with several parameters to enable impairment-aware path computation [13]. Additionally, [19] employed the native RESTful API of ONOS [14] for gathering information about available devices and ports. In particular, a Net2Plan extension specifically developed to interact with ONOS used a RESTful interface based on OpenAPI for parsing the JSON messages into the Net2Plan hierarchical model. We evidenced that, although device model information was available in the planning tool, YANG-modelling limitations due to the 'operational mode' in OpenConfig required further process to provide the input for a potential Net2Plan line engineering algorithm.

A remarkable contribution of INSPIRING-SNI was [21], which introduced the concept of network optimization as a service (OaaS). Network OaaS is based on a classical client-server architecture, and through a RESTful API, holders of network infrastructures (i.e. client role) request the resolution of network resource allocation problems via algorithms, whereas third-party players focus on the development of optimization algorithms (i.e. server role) with potential high-performance computing (HPC) infrastructure for their execution.

Subsequently, [22] demonstrated a Wide-area network (WAN) infrastructure manager (WIM) proof of concept using network OaaS for a multi-SDN scenario. In this work, the WIM was created as a network application capable of communicating with the NBI of multiple SDN controllers. Moreover, the application was able to further expose itself an API modelled after TAPI to an ETSI-based open-source management and orchestration (OSM) solution via WIM plugin, effectively working as a hierarchical mediator/broker.

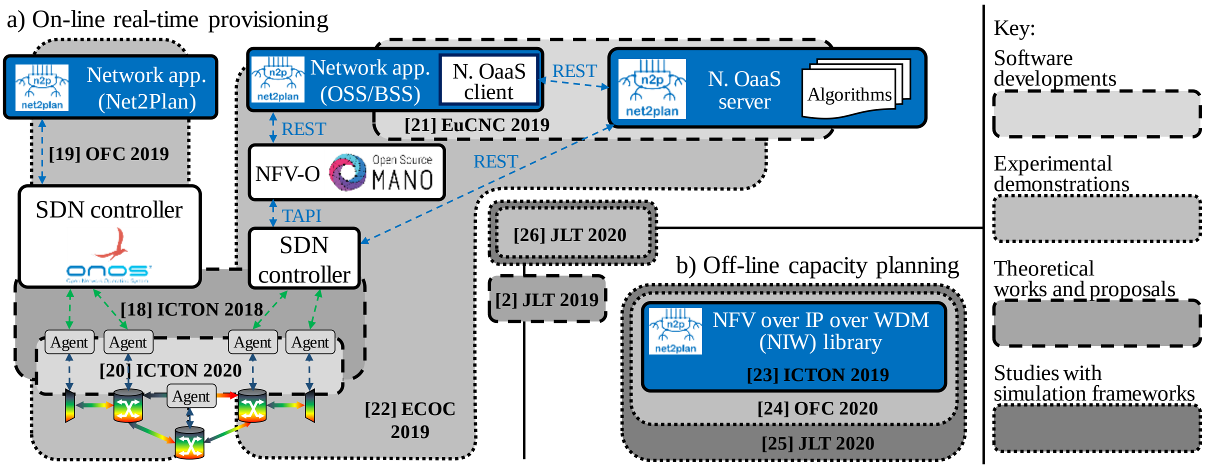

Figure 2. Main contributions of INSPIRING-SNI being works on a) on-line real-time resource provisioning and b) off-line capacity planning and network dimensioning.

The WIM employed an OaaS client to query the OaaS server for the optimal path computation across the network infrastructure (i.e. a practical usage of [21]) and then performed the relevant NBI calls to the connected SDN controllers. In the reported experiment, the WIM was able to leverage two distinct, domain-specific, SDN controllers (one for the packet layer and one for the optical network) to stablish an optimal WAN connecting Virtual Network Functions (VNF) of a single VNF chain distributed among different infrastructure providers.

5. INSPIRING-SNI MAJOR ACHIEVEMENTS

Fig. 2 contextualizes the major achievements of INSPIRING-SNI. A solid line separates the major contributions between a) on-line real-time resource allocation works and b) off-line capacity planning and network dimensioning studies. As described above, Fig. 2a) comprises: the overview of SBI alternatives for the interaction between the SDN controller and the agents [18], a demonstration of a Net2Plan-based network application accessing in real-time optical data-plane parameters thought the entire stack [19], a specific software development for the agents interacting with emulated hardware [20], the proposal of a network OaaS architecture and its interface [21], and its usage in an experimental demonstration [22].

Fig. 2b) illustrates the proposal we made in [23]: the NIW library, which stands for network function virtualization (NFV) over IP over wavelength division multiplexing (WDM). NIW is a library added to the Net2Plan open-source network planning software[3], specifically to model, provision, design and evaluate SDN/NFV networks. NIW was used to generate two remarkable outcomes: a demonstration with a hands-on experience at OFC [24] and a comprehensive techno-economic study for metropolitan optical networks encompassing a realistic 5G traffic model with the evaluation of the filterless technology for the data plane and an agile control plane [25].

Remarkably, INSPIRING-SNI recently reported a combination of an experimental demonstration of on-line real-time resource allocation in Bristol testbed (i.e. based on [22]) and an off-line capacity planning and network dimensioning study based on a realistic model of the Alicante and Murcia Spanish regions [26]. In particular, [26] used the NIW library for dimensioning of SDN/NFV-enabled metropolitan networks paying special attention to the role that latency plays in the capacity planning. Also sitting in-between off-line capacity planning and on-line real-time resource allocation, we covered open-source initiatives for SDN and NFV focusing on their optimization opportunities with strong emphasis on problem modeling, formulation and solving [2].

In parallel, INSPIRING-SNI covered aspects of multi-layer networking and NFV with a series of demonstrations. Specifically, in [27] Net2Plan played the role of operations support system (OSS) / business support system (BSS) for assisting OSM to optimally place the VNFs of a service chain in distributed central offices (COs) interconnected with a simulated metropolitan network. Our work in [28] extended [27] with an ONOS instance governing an emulated network with Mininet. Notably, packet flows, belonging to the service chain instantiated by OSM, traversed the Mininet network for reaching VNFs instantiated in different OpenStack clusters. The main contribution of [29] was a separated Net2Plan plugin devoted to IT resource manager interfacing multiple OpenStack instances for enabling multi-tenant slicing of COs, IT resource visualization and VM migration.

6. SUMMARY

This paper overviewed the achievements of INPIRING-SNI, a Marie Sklodowska-Curie Action that aims at enhancing programmability in optical SDN ecosystems focusing on i) SBI for interacting with optical equipment, ii) NBI for exposing programming abstractions that ease the development of network applications, and iii) network optimization on top of the SDN architecture for an efficient use of the infrastructure.

We contextualized the major contributions generated in the last two years both for on-line real-time resource provisioning and off-line capacity planning, which comprise theoretical analyses, software developments, experimental demonstrations and studies with simulation frameworks.

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